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Parsons Engineering Science, Inc.

1700 Broadway, Suite 900 • Denver, Colorado 80290 • (303) 831-8100 • Fax: (303) 831-8208

11 June 1998

Major Ed Marchand  
AFCEE/ERT  
3207 North Road, Bldg 532  
Brooks AFB, Texas 78235-5363

Subject: Results of Bioventing System Monitoring at Facilities 44625D and 44625E, Cape  
Canaveral Air Station, Florida  
(Contract No. F41624-92-D-8036, Order 17)

Dear Major Marchand:

This letter presents the results of the bioventing system monitoring performed by Parsons Engineering Science, Inc. (Parsons ES) during the week of 11 May 1998 at Facilities 44625D and 44625E, located at Cape Canaveral Air Station (AS), Florida. Soil gas samples were collected and *in situ* respiration testing was performed by Parsons ES to assess the extent of remediation completed during approximately 1 year of full-scale bioventing system operation. The purpose of this letter is to summarize site and bioventing activities to date, present the results of the most recent respiration testing and soil gas sampling event, and make recommendations based on site data and the regulatory status of the site. A site layout and two tables are attached.

## SITE/PROJECT HISTORY

Facilities 44625D and 44625E, the Generator Maintenance Facility, is the site of a former 1,000-gallon underground storage tank (UST) that was used to store waste oil collected in an oil/water separator located within Facility 44625D (Engineering-Science, Inc. [ES], 1994). A layout of the site is provided in Figure 1. In October 1991, the UST was removed, approximately 200 cubic yards of petroleum-contaminated soil was excavated and disposed of offsite, and approximately 4,000 gallons of waste oil and groundwater were pumped from the excavation (CH2M Hill, 1994). The waste oil tank was later replaced with an aboveground storage tank (AST). The waste oil UST is thought to be the primary source of subsurface petroleum contamination at the site; however, facility personnel also have reported that numerous spills and leaks of petroleum products have occurred in the past near the former UST (CH2M Hill, 1994).

Phase I and Phase II assessments were conducted by CH2M Hill (1994; 1995) between 1992 and 1995 to delineate the extent of petroleum hydrocarbon contamination in soils and groundwater in the vicinity of the former waste oil UST. Groundwater sampling performed in January 1992 during the Phase I investigation indicated the presence of benzene, toluene, ethylbenzene, and xylenes (BTEX) and polynuclear aromatic hydrocarbon (PAH) compounds in groundwater at the site; however, subsequent groundwater sampling events indicated that groundwater contamination was minimal (CH2M Hill, 1995). In the Contamination

AQ M01-03-0480

Assessment Report (CAR) (CH2M Hill, 1994) and CAR Addendum (CH2M Hill, 1995) for Facility 44625, CH2M Hill recommended groundwater monitoring only, in conjunction with bioventing treatment of unsaturated soils.

Concurrent with the Phase II investigation, Parsons ES (formerly Engineering-Science, Inc. [ES]) installed bioventing pilot test systems at Facilities 44625D and 44625E in December 1993 as part of the AFCEE Bioventing Initiative program (ES, 1994). The purpose of this project was to determine if *in situ* bioventing would be a feasible cleanup technology for remediating the remaining fuel-contaminated unsaturated zone soils near Facilities 44625D and 44625E. One pilot-scale bioventing system consisting of a vertical vent well (CA3-VW) and three multi-depth monitoring points (CA3-MPA, CA3-MPB, and CA3-MPC) was installed near Facility 44625D and a second bioventing system consisting of one vertical vent well (CA4-VW) and four multi-depth monitoring points (CA4-MPA, CA4-MPB, CA4-MPC, and CA4-MPD) was installed adjacent to Facility 44625E. For each system, the VW screens were set between 3 and 8 feet below ground surface (bgs). Two 6-inch screens were placed at each MP location and consist of a shallow screen at 3 feet bgs and a deeper screen at 5.5 feet bgs. Each system utilized a dedicated 1-horsepower regenerative blower and blower housing and piping configured for air injection into the VWs. A background MP was installed at a separate bioventing system site near Facility 1748 to monitor soil gas conditions in clean, uncontaminated soil. During installation of the pilot-scale systems, soil and soil gas sampling and respiration and air permeability testing were performed at each site. During system startup, the radius of oxygen influence was determined to be approximately 30 feet for each system. Further detail on the pilot test procedures and results can be found in the Interim Bioventing Pilot Test Results Report (ES, 1994), and the Final Tables and Letter of Transmittal from Parsons ES (1996a) to AFCEE.

The 1-year pilot test demonstrated that bioventing is an effective treatment technology for petroleum-contaminated soils present within the unsaturated zone at Facilities 44625D and 44625E; however, elevated water table conditions during the 1-year pilot tests prevented year-round oxygenation of the unsaturated soils designated for treatment. Based on the relatively favorable pilot testing results, the site was included in the AFCEE Extended Bioventing Project for system expansion (two Option 4's) and horizontal vent wells (HVWs) would be used in place of CA3-VW and CA4-VW to minimize the impact of elevated water table conditions. In addition, the AFCEE Extended Bioventing Project provided funding for 1 year of full-scale bioventing system operation followed by soil gas sampling and *in situ* respiration testing (Option 1). In support of the system expansion design, soil gas data were collected at Facilities 44625D and 44625E in June 1996 to fully determine the extent of soils requiring remediation. The area designated for full-scale bioventing treatment is shown on Figure 1.

The full-scale bioventing system was installed by Parsons ES during two separate mobilizations, the first in November 1996, and the second in March 1997. The system was installed in accordance with the Final Remedial Action Plan (RAP) and full-scale system design package (Parsons ES, 1996b). The full-scale system, as initially installed during the November 1996 mobilization included two HVWs (HVWD and HVWE), four new MPs (MPE, MPF, MPG, and MPH), a 2-horsepower regenerative blower, new blower housing, and associated piping, controls, and electrical service at Facilities 44625D and 44625E (Figure 1). System monitoring performed between December 1996 and February 1997 indicated that carbon dioxide and total volatile hydrocarbon (TVH) concentrations in soil gas were reduced

by air injection into HVWD and HVWE; however, oxygen concentrations were not detected above 5 percent in some MP screens placed in highly contaminated soils north of Facility 44625E. As a result, a third HVW (HVW3) was installed in March 1997 and oxygenation of the entire volume of soil designated for remediation was achieved. Initial results for the full-scale bioventing system, along with an operations and maintenance manual and record drawings, were provided by Parsons ES (1997) to AFCEE and the Cape Canaveral AS point of contact for the site (who is assigned to the 45th Civil Engineering Squadron/Environmental Flight at Patrick Air Force Base [AFB], Florida) in May 1997.

The full-scale bioventing system operated continuously from March 1997 until April 1998. In preparation for the Option 1 testing, the blower system was shut down in April 1998 so that site soil and soil gas could return to equilibrium conditions in order to allow comparison of 1-year full-scale system monitoring results with previous monitoring results. Option 1 soil gas sampling and respiration testing was performed at Facilities 44625D and 44625E by Parsons ES the week of 11 May 1998. Soil gas sampling and *in situ* respiration testing results are summarized below, as are recommendations based on this data and a recent Petroleum Action Management Plan (PAMP) meeting between Parsons ES, AFCEE, the Air Force point of contact for the site, and the Florida Department of Environmental Protection (FDEP). Soil sampling results following pilot-scale bioventing system operation (Parsons ES, 1996a and 1996b) and installation of the full-scale bioventing system (Parsons ES, 1997) have been provided previously.

## SOIL GAS CHEMISTRY RESULTS

Field screening and collection of soil gas samples for laboratory analysis were performed on 11 May 1998 following 1 year of full-scale system oxygenation of site soils and 1 month of system shutdown. Soil gas samples were collected and field-screened to assess soil gas concentrations of oxygen, carbon dioxide, and TVH. As with several previous sampling events at the site, the 5.5-foot MP screens were submerged due to elevated water table conditions and soil gas samples only could be collected from the 3-foot depth. Table 1 summarizes the field and laboratory soil gas results from previous sampling events performed during pilot-scale bioventing and full-scale bioventing system design and installation.

Static oxygen concentrations in site soil gas generally did not increase following the first year of full-scale bioventing system operation. While oxygenation of the entire soil volume designated for bioventing treatment was demonstrated following installation of HVW3 and full-scale system startup in March 1997 (Parsons ES, 1997), subsurface conditions at the site continue to return to an anaerobic state following shut down of the blower system. The lack of oxygen in soil gas collected from several MPs in the unsaturated zone soils suggests that aerobic biodegradation of petroleum hydrocarbon contaminants by soil microbial populations is still occurring when oxygen is made available to the subsurface (i.e. provided through air injection bioventing). Elevated carbon dioxide concentrations in site soil gas further suggest that aerobic biodegradation is occurring in site soils and carbon dioxide is being produced as a by-product of the biodegradation. TVH concentrations generally remained unchanged at the MPs near Facility 44625D (CA3-MPA, CA3-MPB, and CA3-MPC, MPF, and MPG) as compared to November 1996 measurements, but decreased TVH concentrations were evident near Facility 44625E (CA4-MPA, CA4-MPB, CA4-MPC, and MPE).



Analytical soil gas results from the May 1998 sampling event and previous sampling events are shown in Table 1. Low TVH concentrations and low/non-detect BTEX concentrations in soil gas samples collected following 1 year of full-scale bioventing system oxygenation of site soils continue to indicate that the majority of petroleum hydrocarbon contamination in site soils is composed of non-volatile, higher molecular weight aliphatic (saturated) and multi-ring aromatic hydrocarbons (PAHs). A soil sample collected from MPE during full-scale system installation in November 1996 (Parsons ES, 1997) indicated that PAHs such as chrysene (654 micrograms per kilogram [ $\mu\text{g/kg}$ ]), dibenz(a,h)-anthracene (372  $\mu\text{g/kg}$ ), fluoranthene (138  $\mu\text{g/kg}$ ), and pyrene (448  $\mu\text{g/kg}$ ) are present in site soils north of Facility 44625E near MPE; however, concentrations of these contaminants were generally less than FDEP (1997) target cleanup levels for these compounds prior to initiation of full-scale bioventing system operation. In addition, PAH compounds have been shown to be susceptible to bioventing (Leeson and Hinchee, 1995; Lund *et al.*, 1991; Hinchee and Ong, 1992; Alleman *et al.*, 1995) and it is likely that the PAH concentrations in soil north of Facility 44625E have been further reduced during full-scale bioventing system operation.

## RESPIRATION TEST RESULTS

As part of the Option 1 field effort, *in situ* respiration testing was performed at the site between 12 and 14 May 1998 in accordance with protocol procedures (Hinchee, *et al.*, 1992). Prior to the test, air was injected for approximately 20 hours into four MPs (CA4-MPA, CA4-MPB, CA4-MPC, and MPE) using 1-cubic foot per minute pumps to locally oxygenate soils in the vicinity of these points. Following air injection, changes in oxygen, carbon dioxide, and TVH soil gas concentrations were monitored over a 25-hour period. Observed rates of oxygen utilization were then used to estimate aerobic fuel biodegradation rates at the site. Biodegradation rates were calculated using a soil moisture content of 11.5 percent, which is the average soil moisture measured in soil during the first year of pilot-scale bioventing activities. Table 2 summarizes the respiration and fuel biodegradation rates determined during May 1998 field event and compares them to rates determined during pilot-scale bioventing.

As is evident from Table 2, *in situ* respiration and fuel biodegradation rates have not decreased significantly as a result of the first year of full-scale bioventing system operation. Observed oxygen utilization rates at the site have remained relatively unchanged since the beginning of pilot-scale bioventing system operation in January 1994. As with the depleted static oxygen concentrations measured in site soil gas, respiration testing results indicate that aerobic biodegradation of petroleum hydrocarbons in unsaturated zone soils continues to be enhanced by the introduction of oxygen. Oxygen utilization and fuel biodegradation rates typically decrease with continued bioventing as the lighter, more readily biodegraded hydrocarbons (BTEX) are preferentially destroyed over more biologically recalcitrant, higher molecular weight hydrocarbons. While site data confirm little to no BTEX contamination remains in site soils, it also suggests that the remaining waste oil contaminants (PAHs) continue to create a significant oxygen demand for sustained aerobic biodegradation. Respiration testing results indicate that further biodegradation of the residual petroleum hydrocarbon contaminants in site soils could be achieved; however, further soils treatment at the site is unnecessary based on the low environmental risk posed by these contaminants and the current regulatory status of the site (discussed below).

## RECOMMENDATIONS

Residual concentrations of PAH compounds in site soils pose little risk at the site. As such, it was determined during the April 1998 PAMP meeting attended by officials from FDEP, AFCEE, Patrick AFB Environmental Flight, and Parsons ES that no further site remediation is necessary because the site has been classified by the State of Florida as requiring no further action (NFA). Patrick AFB personnel may want to continue to operate the system to further reduce residual petroleum concentrations in soil, but there is no regulatory requirement to do so. During the April 1998 PAMP meeting, Patrick AFB personnel expressed interest in having the blower system at Facilities 44625D and 44625E disconnected in order to use the blower at another Cape Canaveral AS or Patrick AFB site. Personnel from Parsons ES will be at Cape Canaveral AS in July 1998 to perform confirmation sampling at Facility 1748 and can disconnect electrical power and the blower manifold piping and prepare the blower for transport at that time.

This report represents the final deliverable for the Facilities 44625D and 44625E site under the AFCEE Extended Bioventing Program. If you have any questions or comments regarding this site, please feel free to contact the site manager, Mr. Steve Archabal in our Phoenix office at (602) 852-9110, or me at (303) 831-8100. Coordination of blower disconnection and preparation for offsite transport should be directed to Mr. Archabal at (602) 852-9110.

Sincerely,  
PARSONS ENGINEERING SCIENCE, INC.



John Ratz  
Project Manager

cc: E. Worth (45 CES/CEV, Patrick AFB)  
S. Archabal (Parsons ES - Phoenix)  
File 726876.26210.E Letter Results Report

Attachments

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- Parsons ES. 1997. Letter Results Report to Major Marchand at AFCEE/ERT, Subject: Operation and Maintenance Manual, Record Drawings, and Summary of Initial Results for the Expanded Bioventing System Installed at Facilities 44625D and 44625E; Horizontal Vent Well Installation at Facility 1748, Cape Canaveral AS, Florida. Denver, Colorado. 30 May.



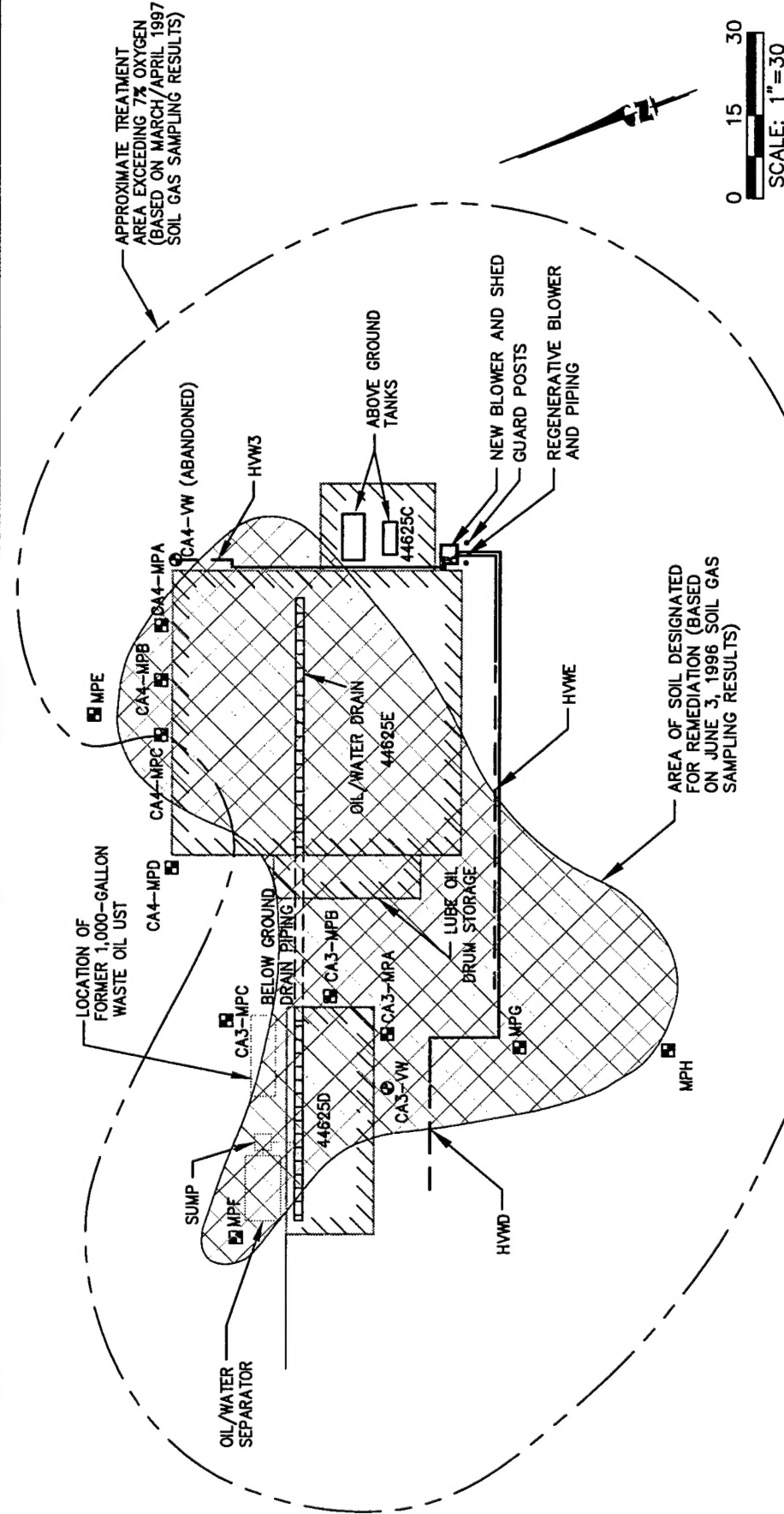


FIGURE 1

# SITE LAYOUT AND EFFECTIVE TREATMENT AREA

Facilities 44625D and 44625E  
Cape Canaveral AS, Florida

**PARSONS  
ENGINEERING SCIENCE, INC.**

Denver, Colorado

## LEGEND

- VAPOR MONITORING POINT
- PILOT TEST VENT WELL (UNUSED)
- HEADER PIPE (BURIED)
- - - HORIZONTAL VENT WELL SCREENED INTERVAL
- ▨ CONCRETE PAD

**TABLE 1**  
**SUMMARY OF FIELD AND ANALYTICAL SOIL GAS RESULTS**  
**FACILITIES 44625D AND 44625E**  
**CAPE CANAVERAL AS, FLORIDA**

Sample Location	Sampling Event <sup>a/</sup> (Date)	Depth (feet bgs) <sup>b/</sup>	Field-Screening Data			Laboratory Data <sup>c/</sup>				
			Oxygen (percent)	Carbon Dioxide (percent)	TVH <sup>c/</sup> (ppmv) <sup>d/</sup>	TVH (ppmv)	Benzene (ppmv)	Toluene (ppmv)	Ethyl- benzene (ppmv)	Xylenes (ppmv)
<b>PILOT-SCALE BIOVENTING SYSTEM</b>										
CA3-VW	Initial (1/94)	3-8 <sup>f/</sup>	0.0	16.0	200	350	0.26	0.19	< 0.014 <sup>g/</sup>	1.3
	1-Year (12/95)	3-8 <sup>f/</sup>	NA <sup>h/</sup>	NA	NA	0.18	< 0.002	< 0.002	< 0.002	< 0.002
CA3-MPA	Initial (1/94)	5.5	0.0	15.8	260	510	0.8	0.32	< 0.050	2.2
	1-Year (12/95)	3	0.0	7.0	420	4.4	< 0.002	< 0.002	< 0.002	< 0.002
	1.5-Year (6/96)	3	0.0	13.5	760	-- <sup>i/</sup>	--	--	--	--
	2-Year (11/96)	3	0.0	6.4	200	--	--	--	--	--
	2-Year (11/96)	5.5	0.0	7.0	200	--	--	--	--	--
	3.5-Year (5/98)	3	0.0	16.0	360	0.41	< 0.021	< 0.021	< 0.021	< 0.021
CA3-MPB	Initial (1/94)	5.5	0.0	15.9	280	--	--	--	--	--
	1-Year (12/95)	3	0.0	9.5	460	--	--	--	--	--
	1.5-Year (6/96)	3	0.0	16.5	920	--	--	--	--	--
	2-Year (11/96)	3	0.0	8.0	320	2.3	< 0.002	0.003	0.005	0.002
	2-Year (11/96)	5.5	0.0	7.9	360	--	--	--	--	--
	3.5-Year (5/98)	3	0.0	17.8	400	0.94	< 0.021	< 0.021	< 0.021	< 0.021
CA3-MPC	Initial (1/94)	5.5	0.0	16.9	200	330	< 0.025	0.10	< 0.025	1.2
	1-Year (12/95)	3	16.7	3.5	240	0.090	< 0.002	< 0.002	< 0.002	< 0.002
	1.5-Year (6/96)	3	13.5	5.3	136	--	--	--	--	--
	2-Year (11/96)	3	13.9	4.8	220	--	--	--	--	--
	2-Year (11/96)	5.5	0.0	14.2	340	--	--	--	--	--
	3.5-Year (5/98)	3	16.9	4.0	200	--	--	--	--	--
CA4-VW	Initial (1/94)	3-8 <sup>f/</sup>	11.5	8.0	60	0.25	< 0.002	< 0.002	< 0.002	< 0.002
	1-Year (12/95)	3-8 <sup>f/</sup>	NA	NA	NA	0.15	< 0.002	< 0.002	< 0.002	< 0.002
CA4-MPA	Initial (1/94)	5.5	0.0	16.9	120	320	< 0.052	0.093	< 0.052	0.90
	1-Year (12/95)	3	0.0	10.3	460	0.49	< 0.002	< 0.002	< 0.002	< 0.002
	1.5-Year (6/96)	3	0.0	15.5	12,800	--	--	--	--	--
	2-Year (11/96)	3	0.0	15.0	8,000	2	< 0.011	< 0.011	< 0.011	0.047M <sup>j/</sup>
	2-Year (11/96)	5.5	0.0	15.0	8,400	--	--	--	--	--
	3-Year (5/98)	3	0.0	13.8	360	1.5	< 0.022	< 0.022	< 0.022	< 0.022
CA4-MPB	Initial (1/94)	5.5	0.0	16.0	260	--	--	--	--	--
	1-Year (12/95)	3	0.0	10.8	10,000	--	--	--	--	--
	1.5-Year (6/96)	3	0.0	17.2	> 20,000 <sup>k/</sup>	--	--	--	--	--
	2-Year (11/96)	3	0.0	15.1	> 20,000	26	< 0.011	< 0.011	< 0.011	0.046M
	2-Year (11/96)	5.5	0.0	15.2	> 20,000	--	--	--	--	--
	3-Year (5/98)	3	0.0	18.5	9,600	15	< 0.011	0.014	< 0.011	0.036
CA4-MPC	Initial (1/94)	5.5	0.0	16.0	300	590	0.15	1.5	0.96	5.6
	1-Year (12/95)	3	0.0	11.5	15,000	100	< 0.002	0.004	< 0.002	0.060
	1.5-Year (6/96)	3	0.0	22.0	> 20,000	--	--	--	--	--
	2-Year (11/96)	3	0.0	15.0	> 20,000	7.1	< 0.021	0.024	< 0.021	0.67M
	2-Year (11/96)	5.5	0.0	15.1	> 20,000	--	--	--	--	--
	3-Year (5/98)	3	0.0	18.5	13,600	6.1	< 0.011	0.013	< 0.011	0.012
CA4-MPD	1-Year (12/95)	3	NA	NA	NA	--	--	--	--	--
	1.5-Year (6/96)	3	8.0	8.8	168	--	--	--	--	--
	2-Year (11/96)	3	5.9	11.8	260	--	--	--	--	--
	3-Year (5/98)	3	12.5	6.2	240	--	--	--	--	--
<b>EXPANDED-SCALE BIOVENTING SYSTEM</b>										
MPE	Initial (11/96)	3	0.0	14.0	7,000	66	< 0.021	0.026M	< 0.021	0.19
	1-Year (5/98)	3	0.0	18.5	800	6.6	< 0.011	0.012	< 0.011	0.012
MPF	Initial (11/96)	3	11.6	4.5	300	--	--	--	--	--
	1-Year (5/98)	3	11.5	7.2	200	--	--	--	--	--
MPG	Initial (11/96)	3	18.0	0.9	80	--	--	--	--	--
	1-Year (5/98)	3	14.5	4.8	170	--	--	--	--	--
MPH	Initial (11/96)	3	18.5	1.3	120	--	--	--	--	--
	1-Year (5/98)	3	13.8	4.2	190	--	--	--	--	--

<sup>a/</sup> Sampling events identified based upon approximate cumulative bioventing treatment time at each location.

<sup>b/</sup> Sample depth in feet below ground surface.

<sup>c/</sup> TVH = Total volatile hydrocarbons.

<sup>d/</sup> ppmv = Parts per million, volume per volume.

<sup>e/</sup> Laboratory analysis of soil gas performed using USEPA Method TO-3; TVH referenced to gasoline.

<sup>f/</sup> Vent wells screened from 3 to 8 feet bgs, but the effective screened interval was frequently less than 5 feet due to elevated water table conditions.

<sup>g/</sup> < = Compound analyzed for, but not detected. Number shown represents the laboratory reporting limit.

<sup>h/</sup> NA = Data not available.

<sup>i/</sup> -- = Not sampled.

<sup>j/</sup> M = Reported value may be biased due to apparent laboratory matrix interferences.

<sup>k/</sup> > = Concentration greater than maximum reading on Gas-Tech® Trace Techcor hydrocarbon analyzer.

**TABLE 2**  
**SUMMARY OF RESPIRATION AND FUEL BIODEGRADATION RATES**  
**FACILITIES 44625D AND 44625E**  
**CAPE CANAVERAL AS, FLORIDA**

Location-Depth (feet below ground surface)	Initial (January 1994) <sup>a/</sup>		6-Month (June 1995) <sup>c/</sup>		1-Year (December 1995) <sup>d/</sup>		3-Year (May 1998) <sup>c/d/</sup>	
	Respiration Rate (%O <sub>2</sub> /hour)	Degradation Rate (mg/kg/year) <sup>b/</sup>	Respiration Rate (%O <sub>2</sub> /hour)	Degradation Rate (mg/kg/year)	Respiration Rate (%O <sub>2</sub> /hour)	Degradation Rate (mg/kg/year)	Respiration Rate (%O <sub>2</sub> /hour)	Degradation Rate (mg/kg/year)
<b>Facility 44625D</b>								
CA3-MPA-3	NS <sup>e/</sup>	NC <sup>f/</sup>	0.37	1,400	0.28	500	NS	NC
CA3-MPA-5.5	0.40	2,400	0.25	950	NS	NC	NS	NC
CA3-MPB-3	NS	NC	0.47	1,900	0.37	840	NS	NC
CA3-MPB-5.5	0.26	1,600	0.55	2,300	NS	NC	NS	NC
CA3-MPC-3	NS	NC	0.28	1,100	0.05	110	NS	NC
CA3-MPC-5.5	0.50	3,100	1.02	4,100	NS	NC	NS	NC
<b>Facility 44625E</b>								
CA4-MPA-3	NS	NC	0.28	1,200	0.18	370	0.30	1,200
CA4-MPA-5.5	0.19	1,200	0.30	1,200	NS	NC	NS	NC
CA4-MPB-3	NS	NC	1.38	5,700	0.50	1,200	1.89	7,600
CA4-MPB-5.5	0.16	930	1.50	6,200	NS	NC	NS	NC
CA4-MPC-3	NS	NC	NS	NC	1.38	3,400	1.08	4,400
CA4-MPC-5.5	0.17	1,000	NS	NC	NS	NC	NS	NC
MPE-3	NA <sup>g/</sup>	NA	NA	NA	NA	NA	0.59	2,500

<sup>a/</sup> Initial respiration testing performed in January 1994, but system operation did not begin until October 1994.

<sup>b/</sup> Milligrams of hydrocarbons per kilogram of soil per year.

<sup>c/</sup> Assumes moisture content of the soil is average of initial and 1-year moistures.

<sup>d/</sup> Unable to perform respiration testing at 5.5 foot depths due to flooding/elevated water table.

<sup>e/</sup> NS = not sampled.

<sup>f/</sup> NC = not calculated.

<sup>g/</sup> NA = not applicable; MPE installed in November 1996 as part of the expanded-scale bioventing system.